

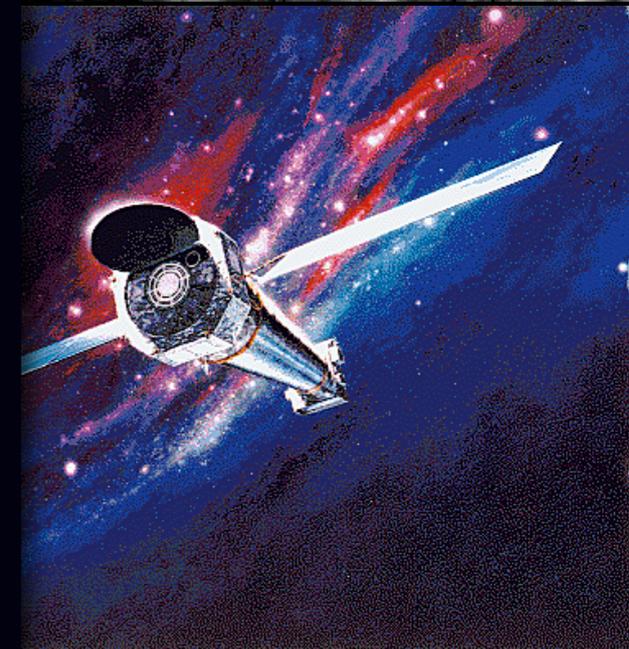
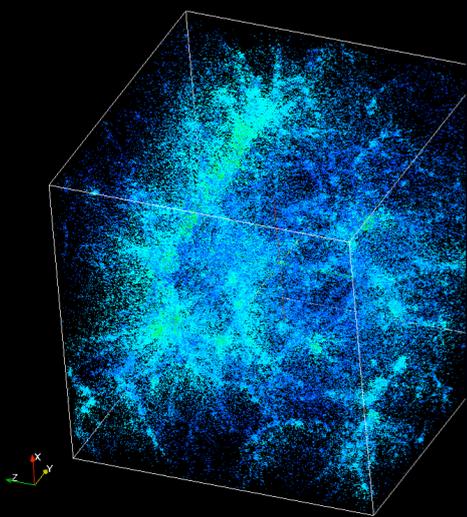
Constellation-X as a Dark Matter Detector

Kevork Abazajian



University of Maryland

Constellation-X FST Meeting
December 20, 2006



The Cosmological Dark Matter Problem

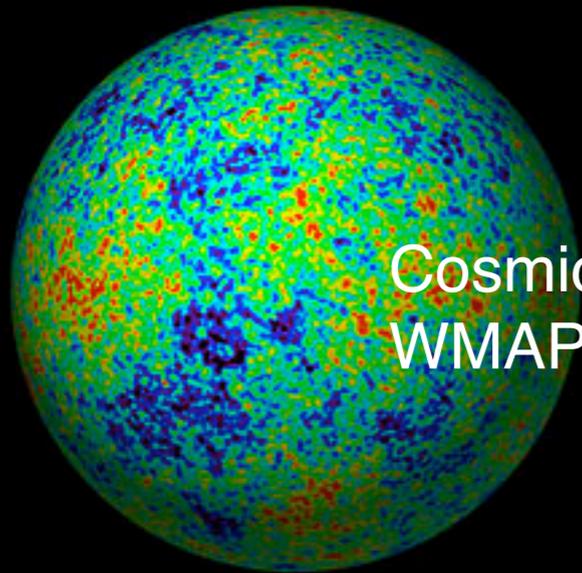
First indication: velocity of
outer galaxies in a cluster

$$GM(r) = v^2 r$$

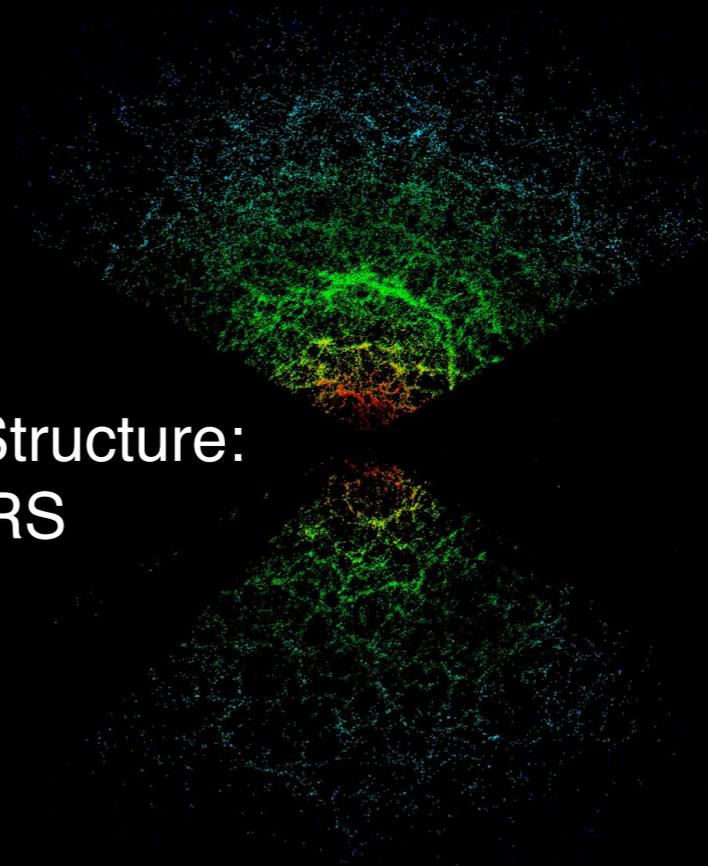
Zwicky (1933):
the “dunkel-masser”/ the “dark matter”



Dark Matter Today



Cosmic Microwave Background:
WMAP, ACBAR, CBI, Boomerang



Large Scale Structure:
SDSS, 2dFGRS

$$\Omega_{\text{DM}} = 0.20^{+0.018}_{-0.017}$$

WMAP3 + SDSS LRG 3D P(k)

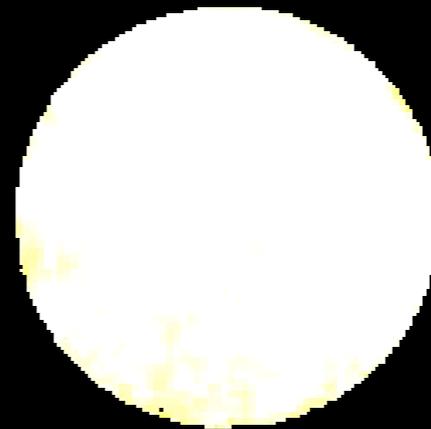
Summary

- Warm Dark Matter has become the “**standard alternate**” **cosmological structure formation** scenario, as it may resolve many problems in structure formation
- Sterile Neutrino Dark Matter is a **natural, minimal** WDM *and* CDM candidate
- Sterile Neutrino Dark Matter, in the standard production scenarios, is **detectable or *potentially* excludable** with *Constellation-X* **and by no other means**

$R = 6,0 \text{ Mpc}$

$z = 10,155$

The CDM *Ansatz*



$a = 0,090$

diemand 2003

Problems in Cold Dark Matter?

- Halo Substructure:
satellite galaxies and sub-halos
(Klypin et al 1999; Moore et al 1999)
- Halo Cores and Densities:
(Moore 1994; Gilmore et al 2006)
- Void Galaxy abundances
(Peebles 2001)
- Angular Momentum Problem
(Navarro & Benz 1991;
Sommer-Larsen & Dolgov 2001)
- Disk Dominated Galaxy Formation
(Governato et al 2002)

Is the Dark Matter *slightly Warm*?



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Dark matter comes out of the cold

By Jonathan Amos
BBC News science reporter

Astronomers have for the first time put some real numbers on the physical characteristics of dark matter.

This strange material that dominates the Universe but which is invisible to current telescope technology is one of the great enigmas of modern science.

That it exists is one of the few things on which researchers have been certain.

But now an Institute of Astronomy, Cambridge, team has at last been able to place limits on how it is packed in space and measure its "temperature".

"It's the first clue of what this stuff might be," said Professor Gerry Gilmore. "For the first time ever, we're actually dealing with its physics," he told the BBC News website.

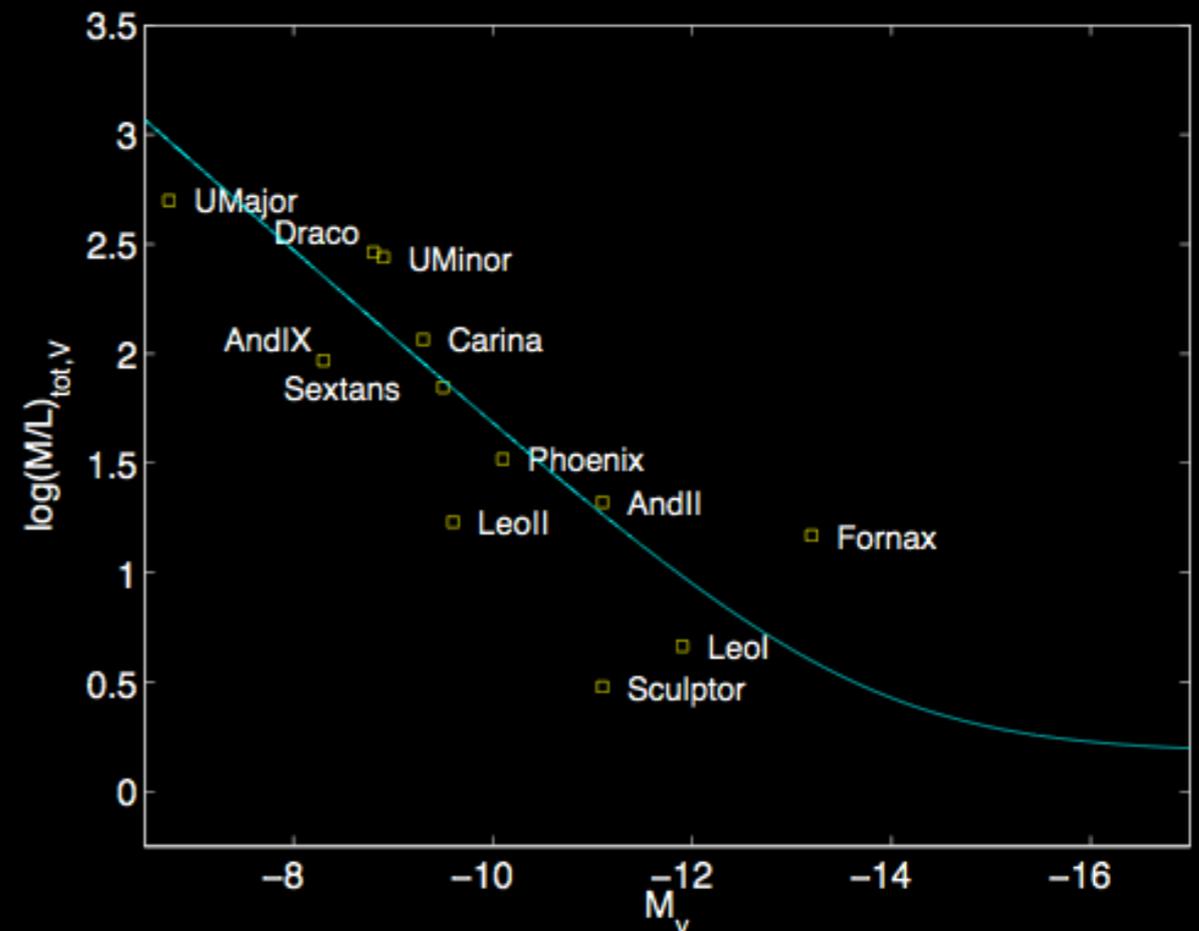
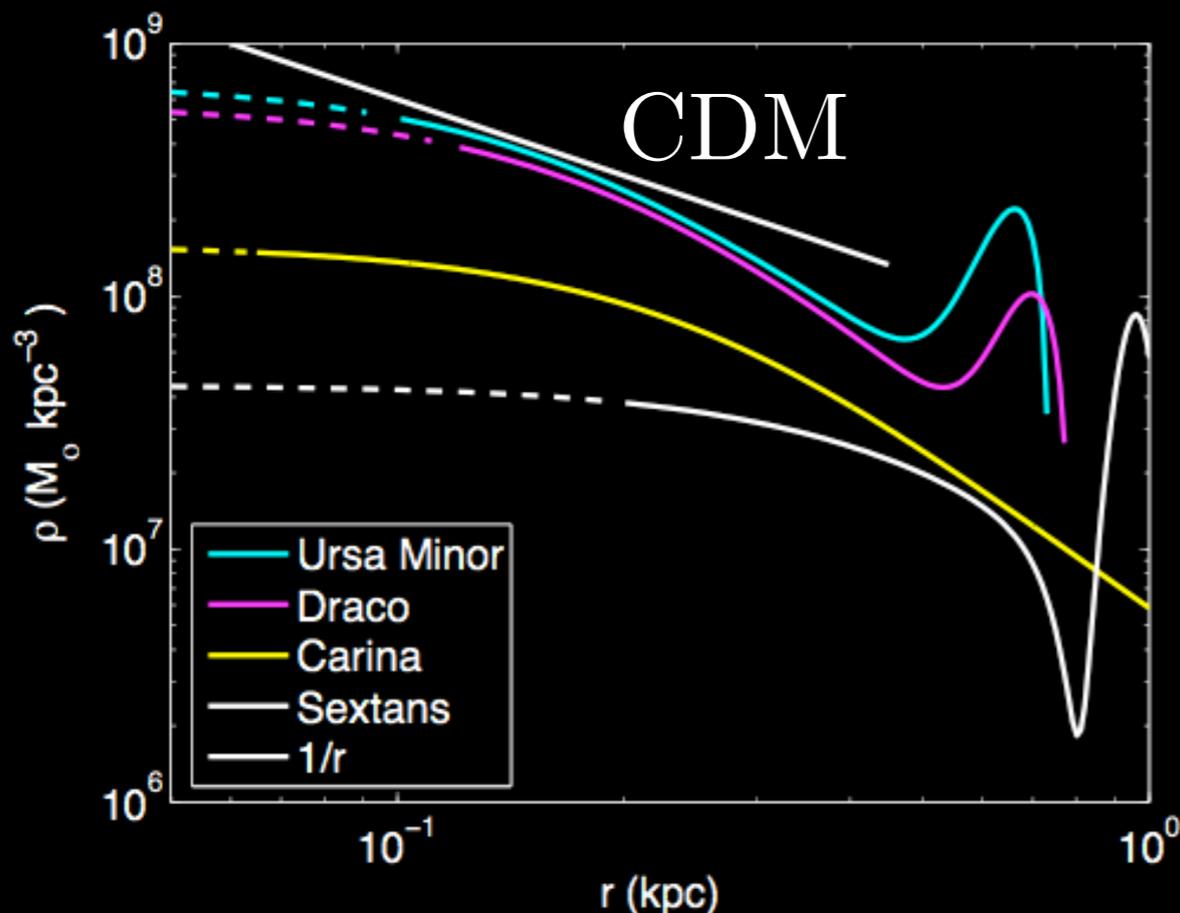
Science understands a great deal about what it terms baryonic matter - the "normal" matter which makes up the stars, planets and people - but it has struggled to comprehend the main material from which the cosmos is constructed.



The British team used 23 nights of observing time on the VLT

Dwarf Spheroidal Density Profiles from Radial Stellar Velocity Dispersion

- All dwarf spheroidals studied are consistent with NFW and cored profiles, except for UMi, “only consistent with cored profile” [Gilmore et al., astro-ph/0608528]
- Presence of core is consistent with mass of [Strigari et al, 2006]: $0.5 \text{ keV} \lesssim m_s \lesssim 1.5 \text{ keV}$

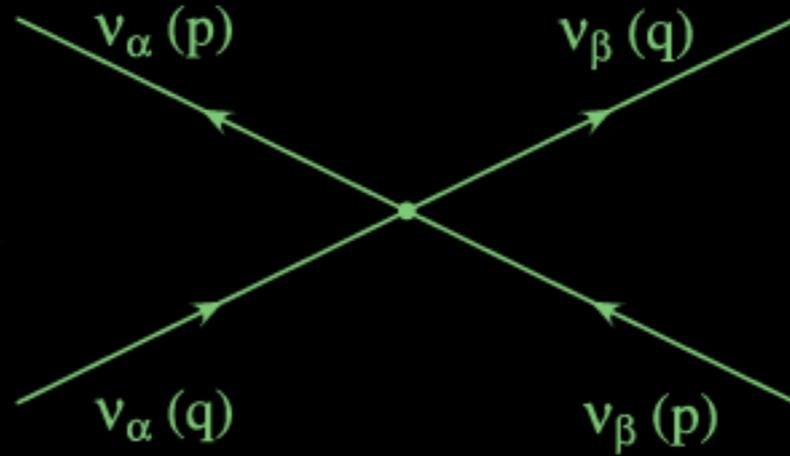


Sterile Neutrinos

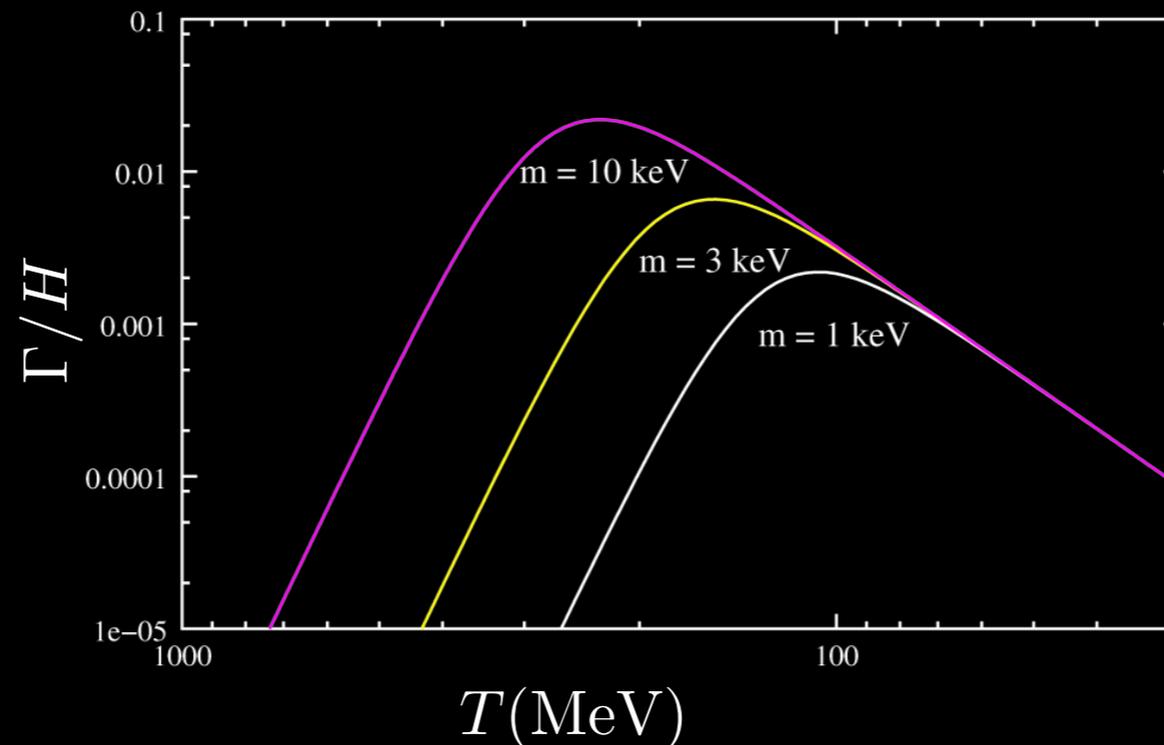
Beyond the Standard Model of Particle Physics

- ν_s Phenomenological Insertion of Majorana & Dirac Mass Terms of Comparable Magnitude (e.g. ν MSM)
- ν_s Left-Right Symmetric Models (Pati & Salam 1974; Mohapatra & Pati 1975)
- ν_s Higher Dimensional Operators in String-Inspired models (Langacker 1998)
- ν_s Bulk Fermions in Large Extra Dimensions (ADD; Dvali & Smirnov 2000)
- ν_s Axino in R-parity Violating Minimal Supersymmetric Models (Chun & Kim 1999)

Sterile Neutrino Dark Matter Production



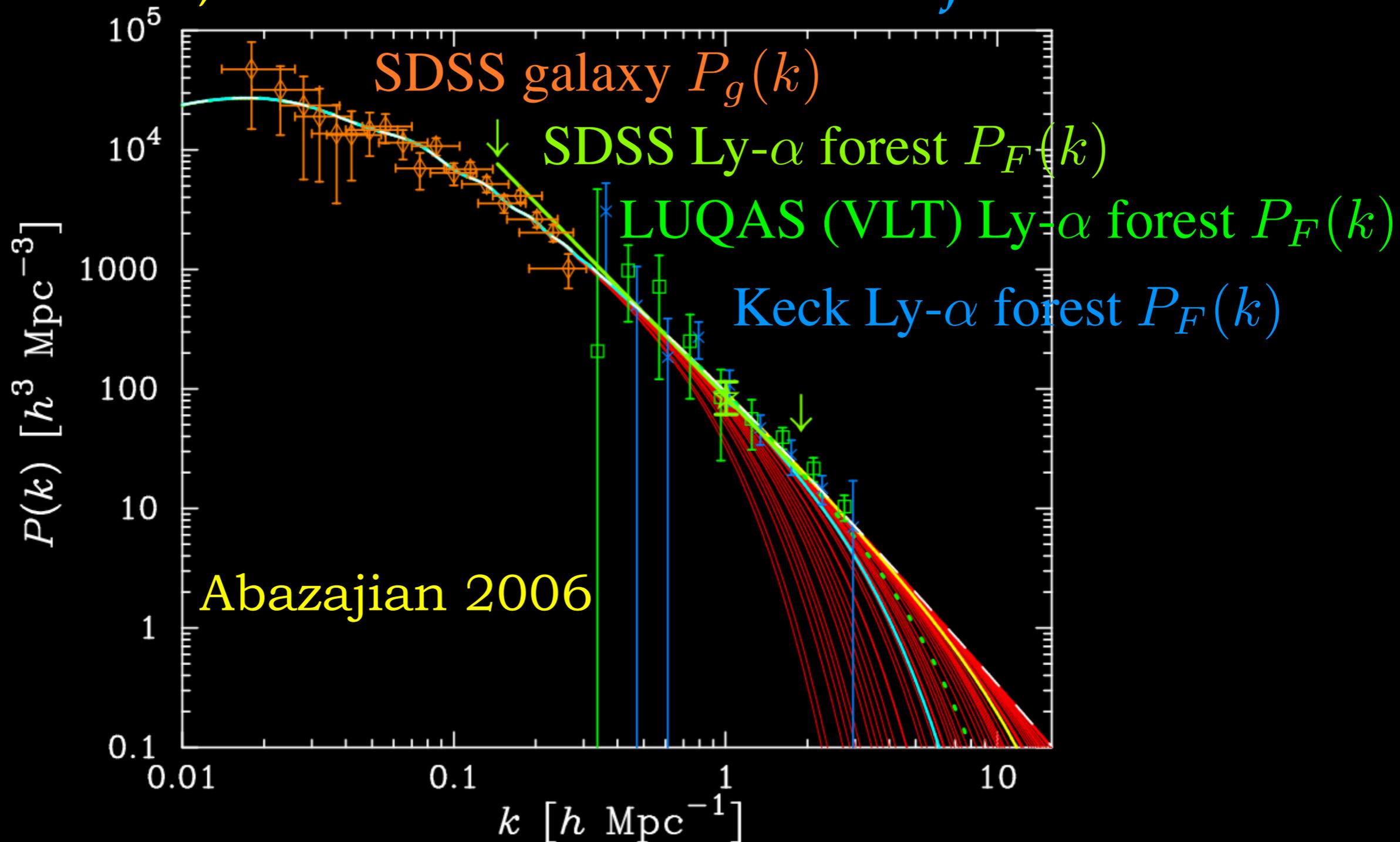
$$\frac{\partial}{\partial t} f_s(p, t) - H p \frac{\partial}{\partial p} f_s(p, t) \approx \Gamma(\nu_\alpha \rightarrow \nu_s; p, t) [f_\alpha(p, t) - f_s(p, t)]$$



Dodelson & Widrow (1994)
 Abazajian et al (2001)
 Abazajian (2006)

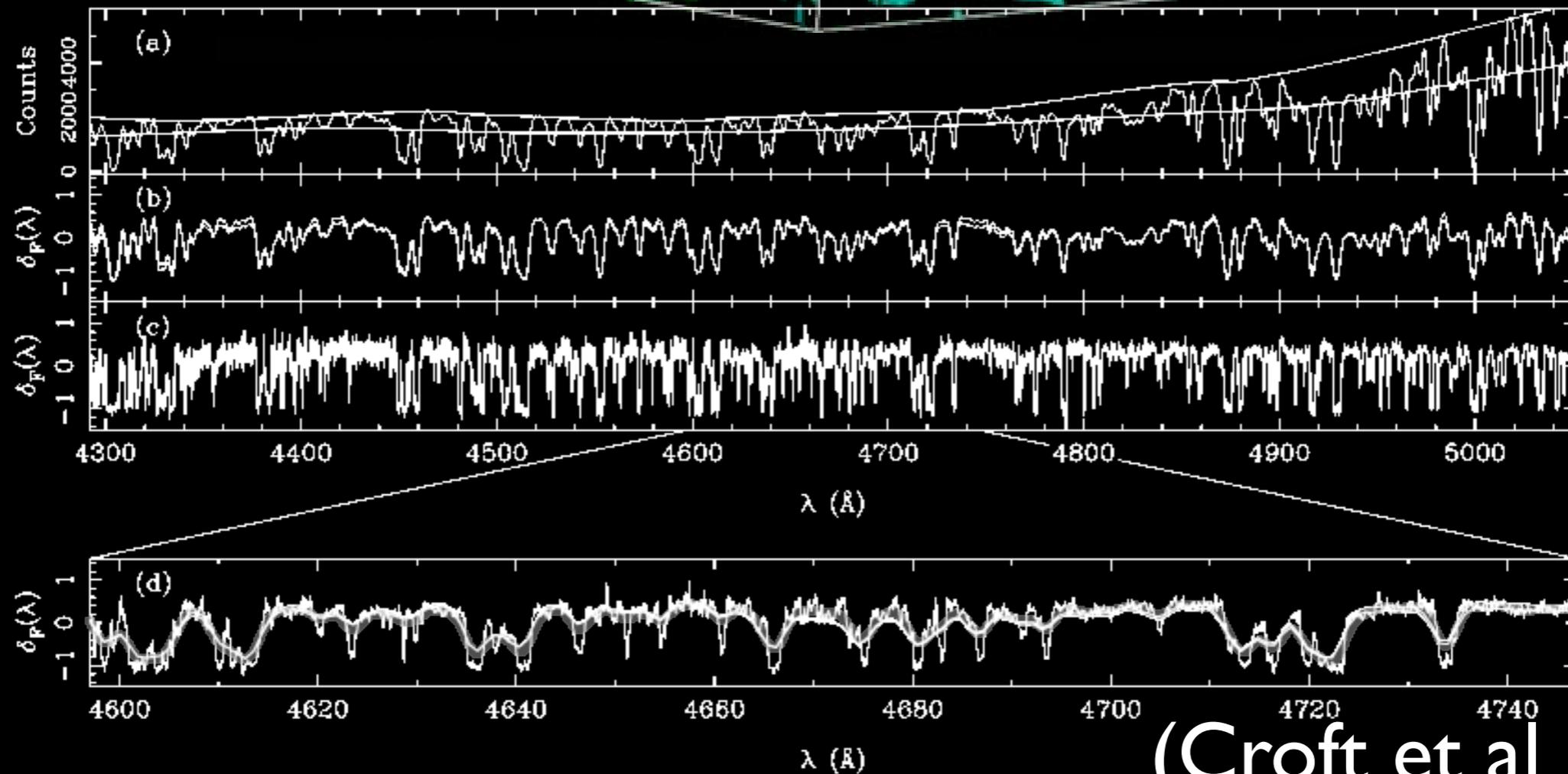
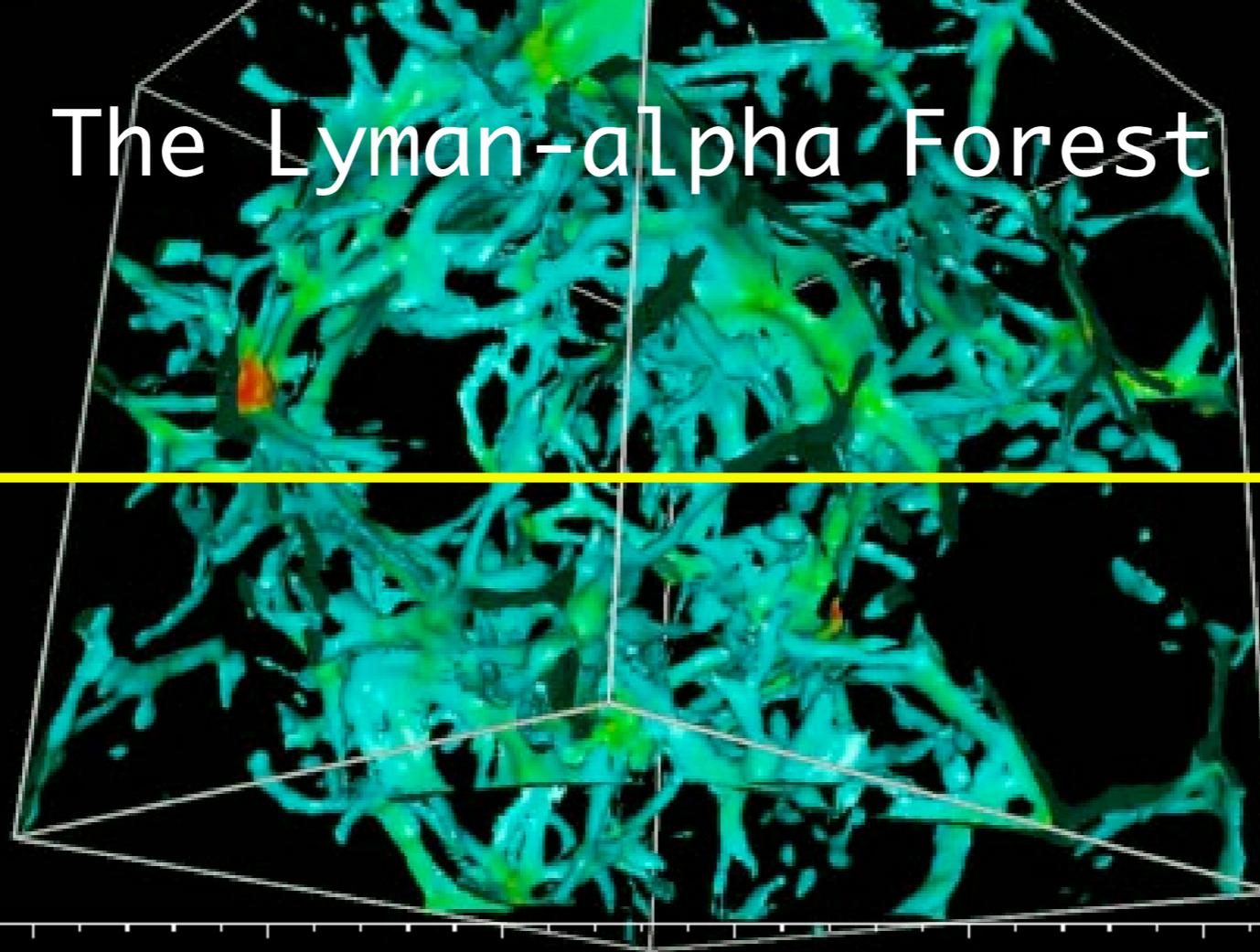
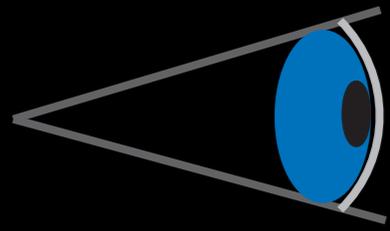
How warm is too warm?

Or, where does the CDM ansatz fail?



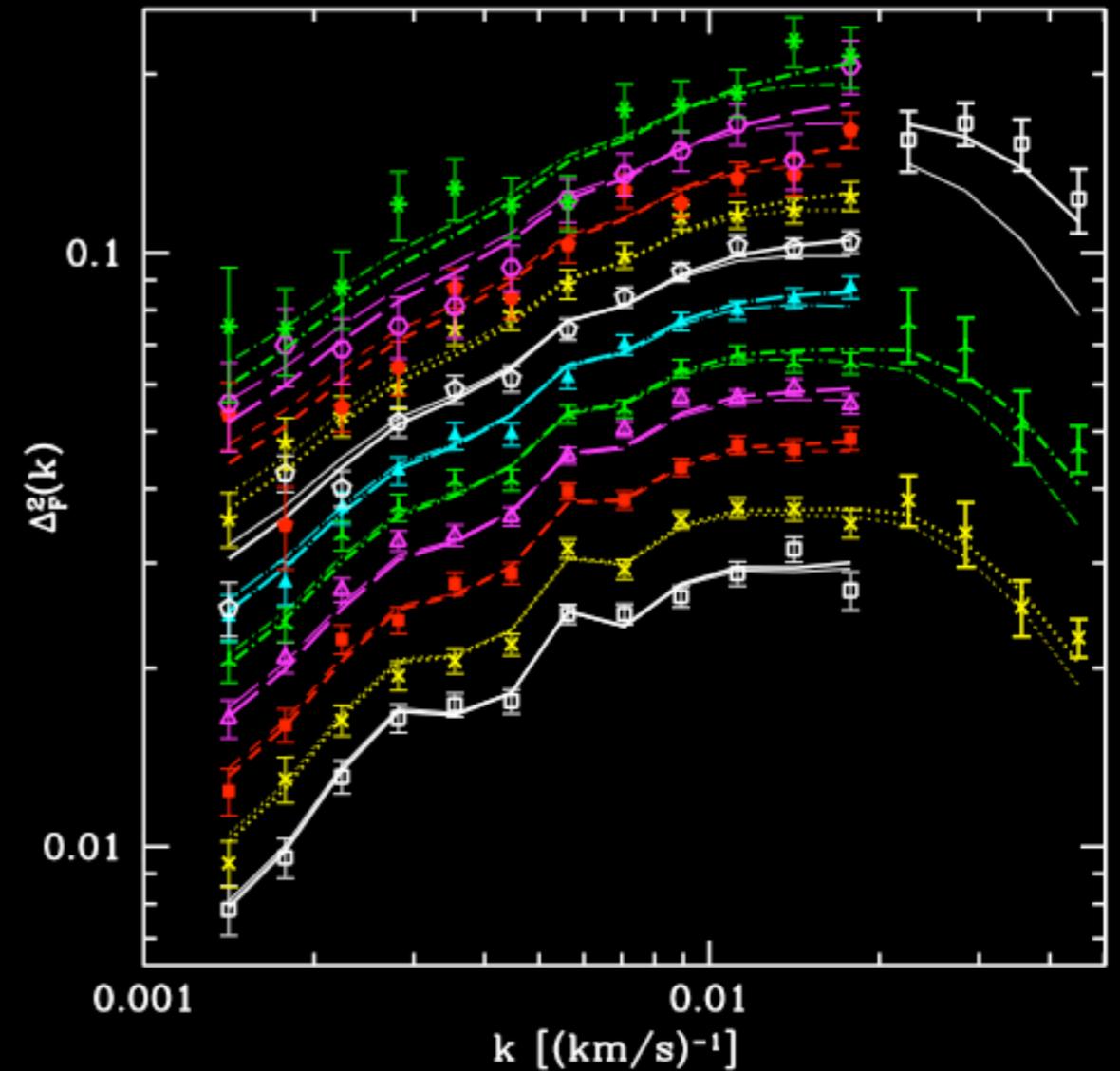
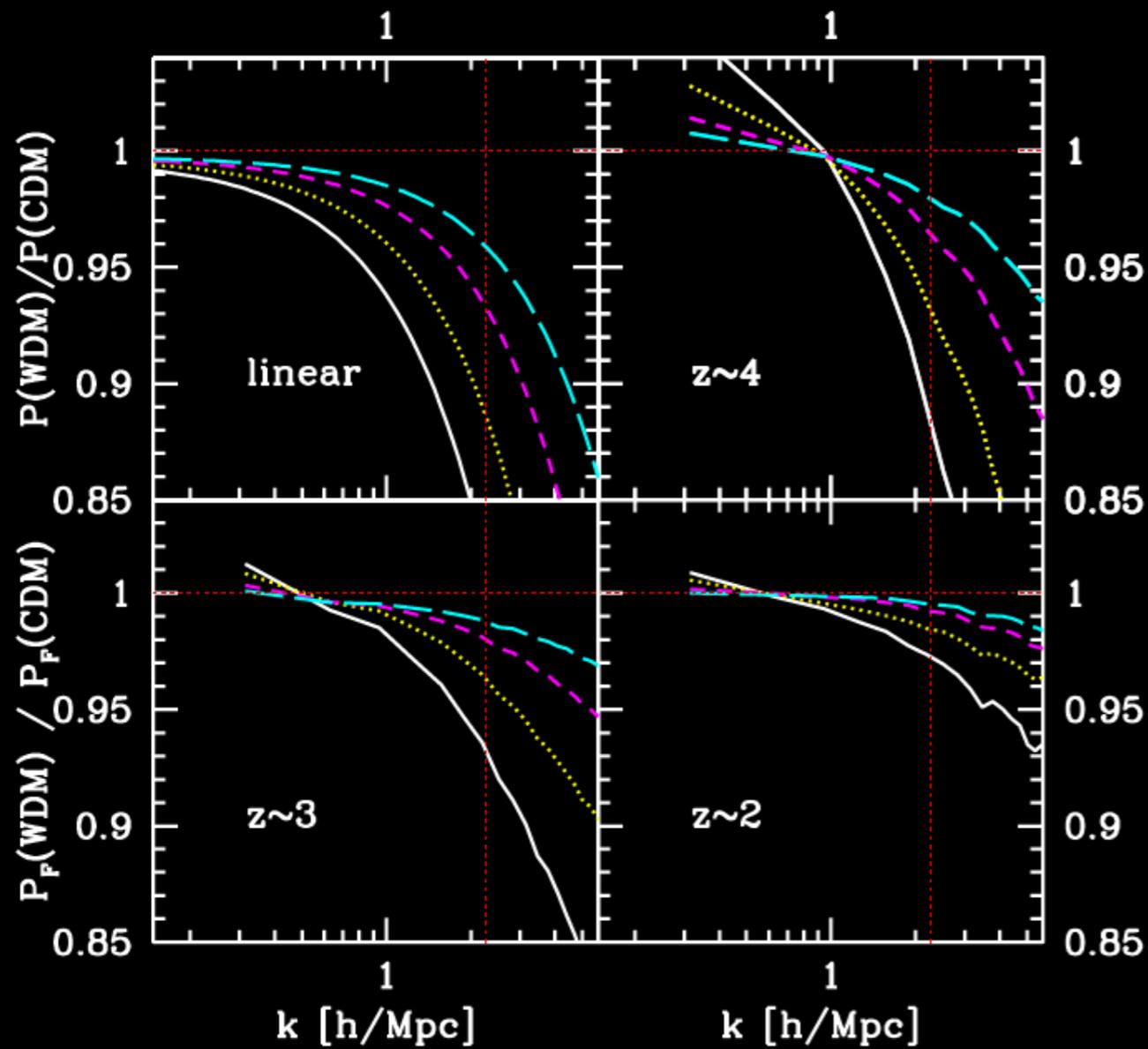
- SDSS 3D $P(k)$ Main Galaxies (Tegmark et al 2003)
- SDSS Lyman-alpha forest (McDonald et al 2005)
- High-Resolution Lyman-alpha forest (Viel, Haehnelt & Springel 2004)
- CMB: WMAP, ACBAR, CBI, VSA, BOOMERANG-2K2

The Lyman- α Forest



(Croft et al 1999)

Stringent Lyman-alpha Forest Constraints?



$$m_s > 14 \text{ keV}$$

Seljak et al 2006: WMAP1 + SDSS $P_g(k)$ + Ly α + HR

$$m_s > 9 \text{ keV}$$

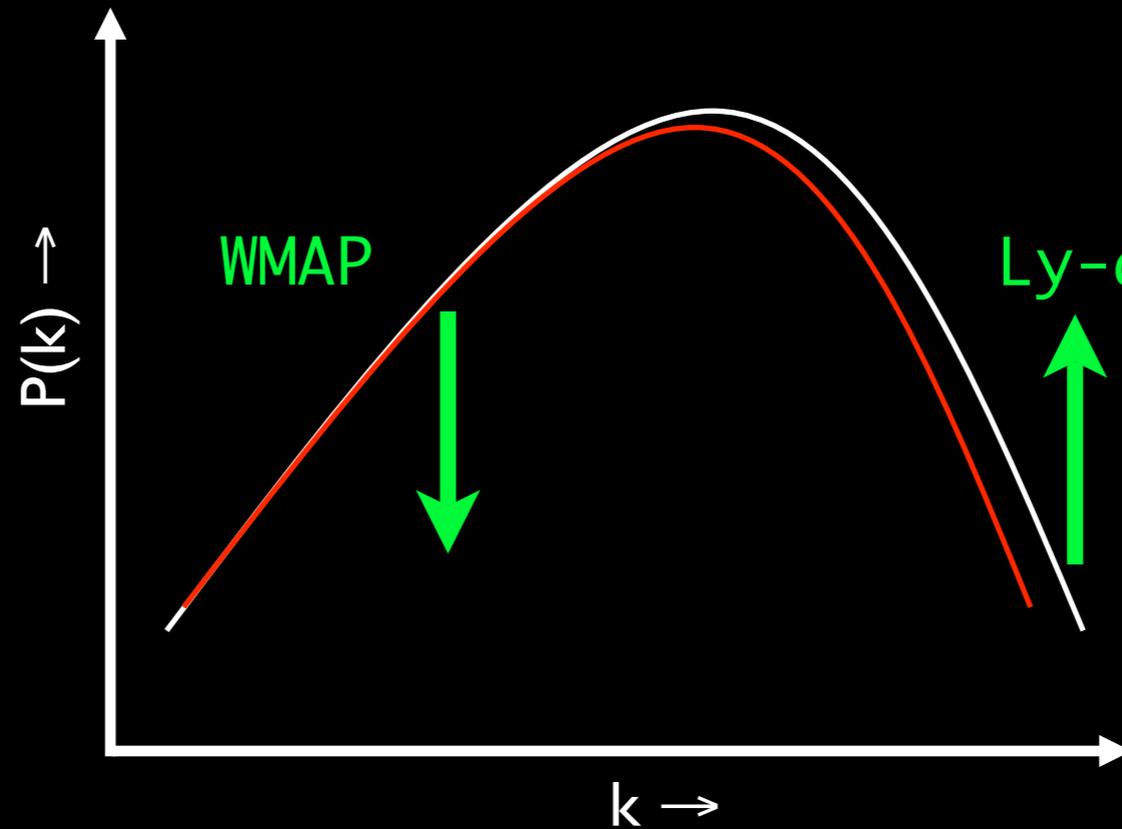
Viel et al 2006: WMAP3 + CMB + 2dFGRS + SDSS Ly α

Both depend on the McDonald et al. (2006) SDSS $P_F(k)$ Measurement

SDSS Lyman-alpha Constraints (Seljak et al 2006)

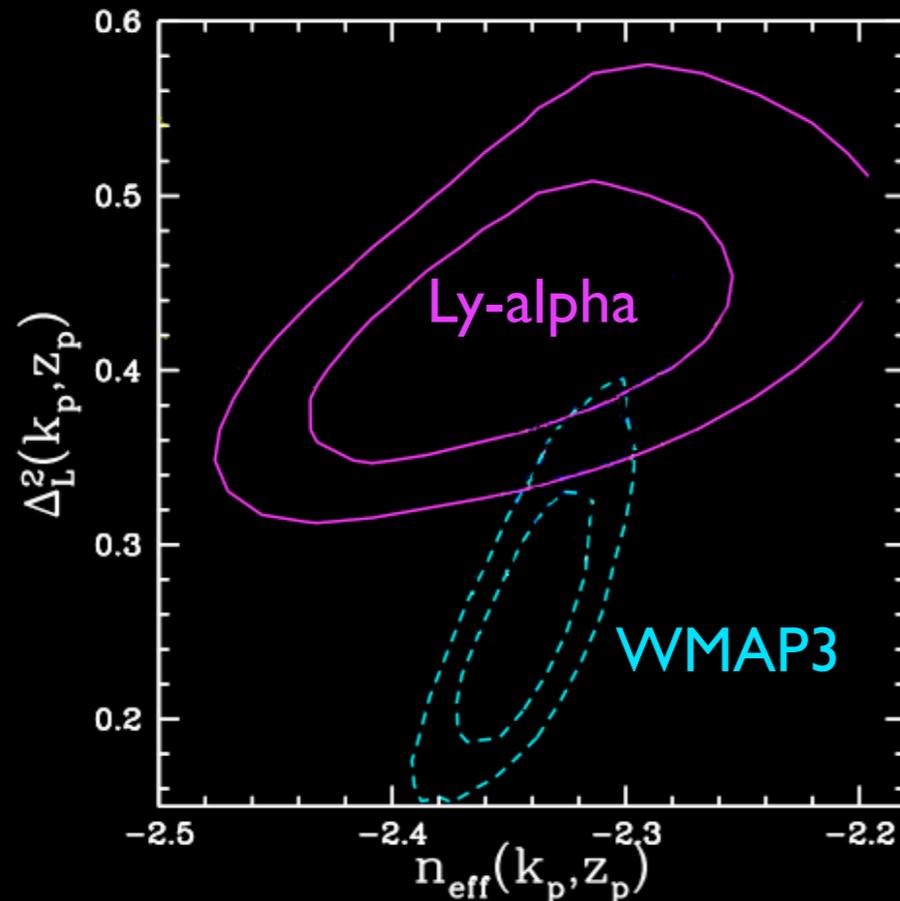
WMAP3:

$$\sigma_8 = 0.74^{+0.05}_{-0.04}$$



SDSS Ly-alpha
(Seljak et al
2003):
 $\sigma_8 = 0.9^{+0.03}_{-0.03}$

1% likely!



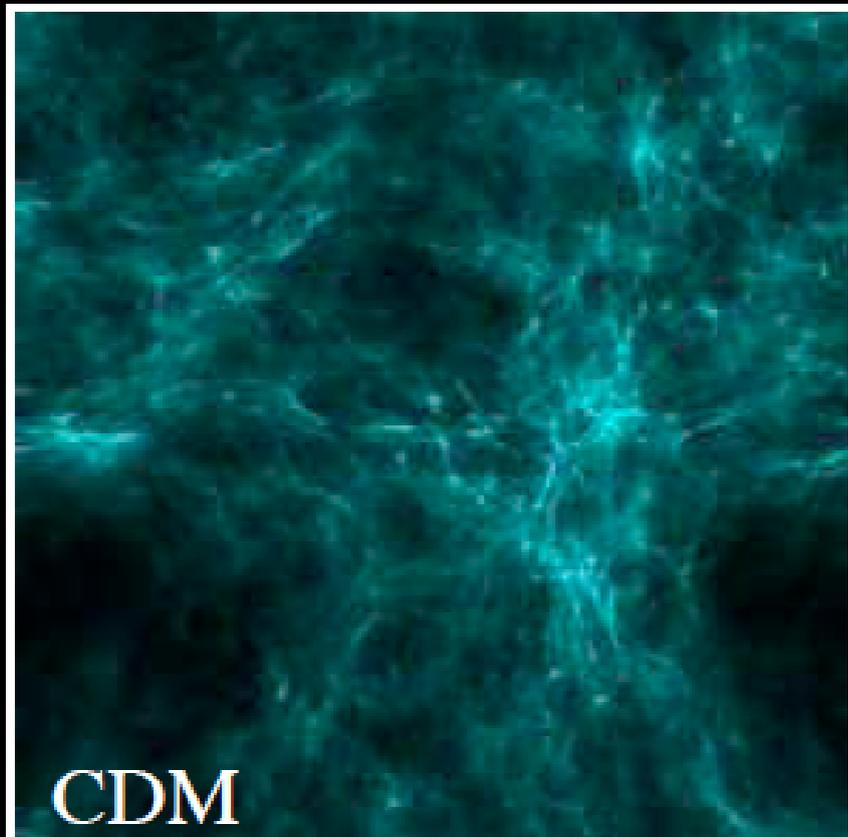
$$N_\nu = 5.4^{+0.4}_{-0.6} \quad \text{Seljak et al. Ly}\alpha$$

$$N_\nu = 3.08^{+0.74}_{-0.68}$$

BBN, Cyburt et al. 2004

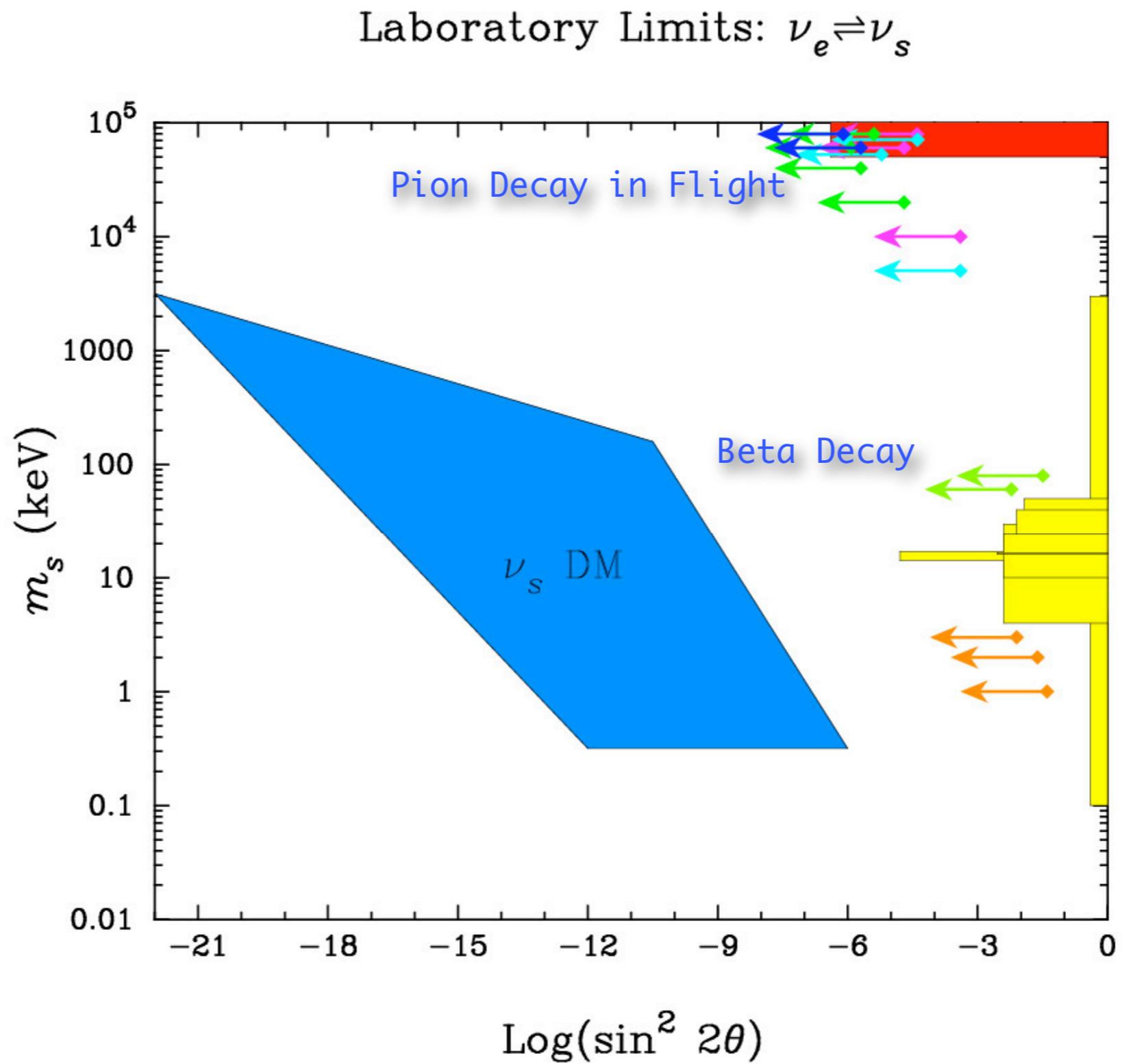
$$N_\nu = 3.04 \quad (\text{standard model})$$

Reionization & the “First Stars”

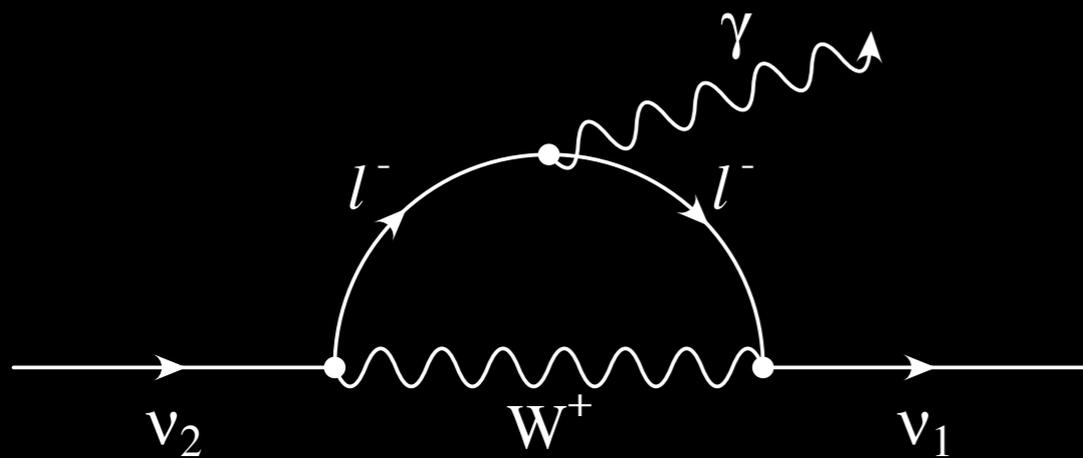


- H_2 formation from ionizing flux of sterile neutrino decay (Biermann & Kusenko, PRL, 2006)
- Can catalyze star formation (Maltoni et al 2006)

Laboratory Limits



Radiative Decay in the X-ray

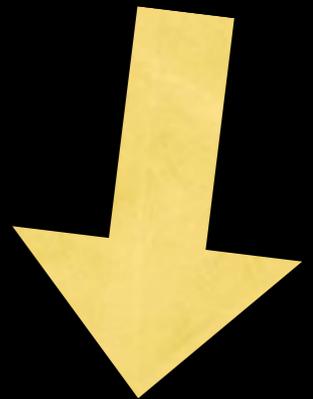


$$\nu_i \rightarrow \nu_j + \gamma$$

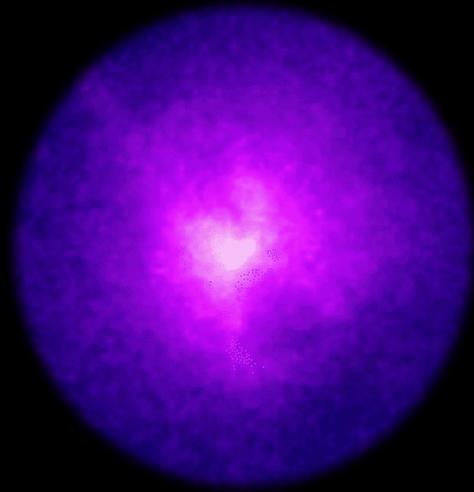
$$E_\gamma = \frac{m_s}{2} \sim 1 \text{ keV}$$

Pal & Wolfenstein 1981

$$\Gamma_\gamma(m_s, \sin^2 2\theta) = 1.36 \times 10^{-29} \text{ s}^{-1} \left(\frac{\sin^2 2\theta}{10^{-7}} \right) \left(\frac{m_s}{1 \text{ keV}} \right)^5$$



Dark Matter Halos as Particle Reservoirs: Detecting Decaying Dark Matter



$\sim 10^{70}$ particles



Background:

- X-ray continuum
- Compact Objects
- Instrumental

Signal:

$$F \propto \int d\Omega \left[\text{DM density/distance}^2 \right] \propto J[\Delta\Omega(\theta)]$$

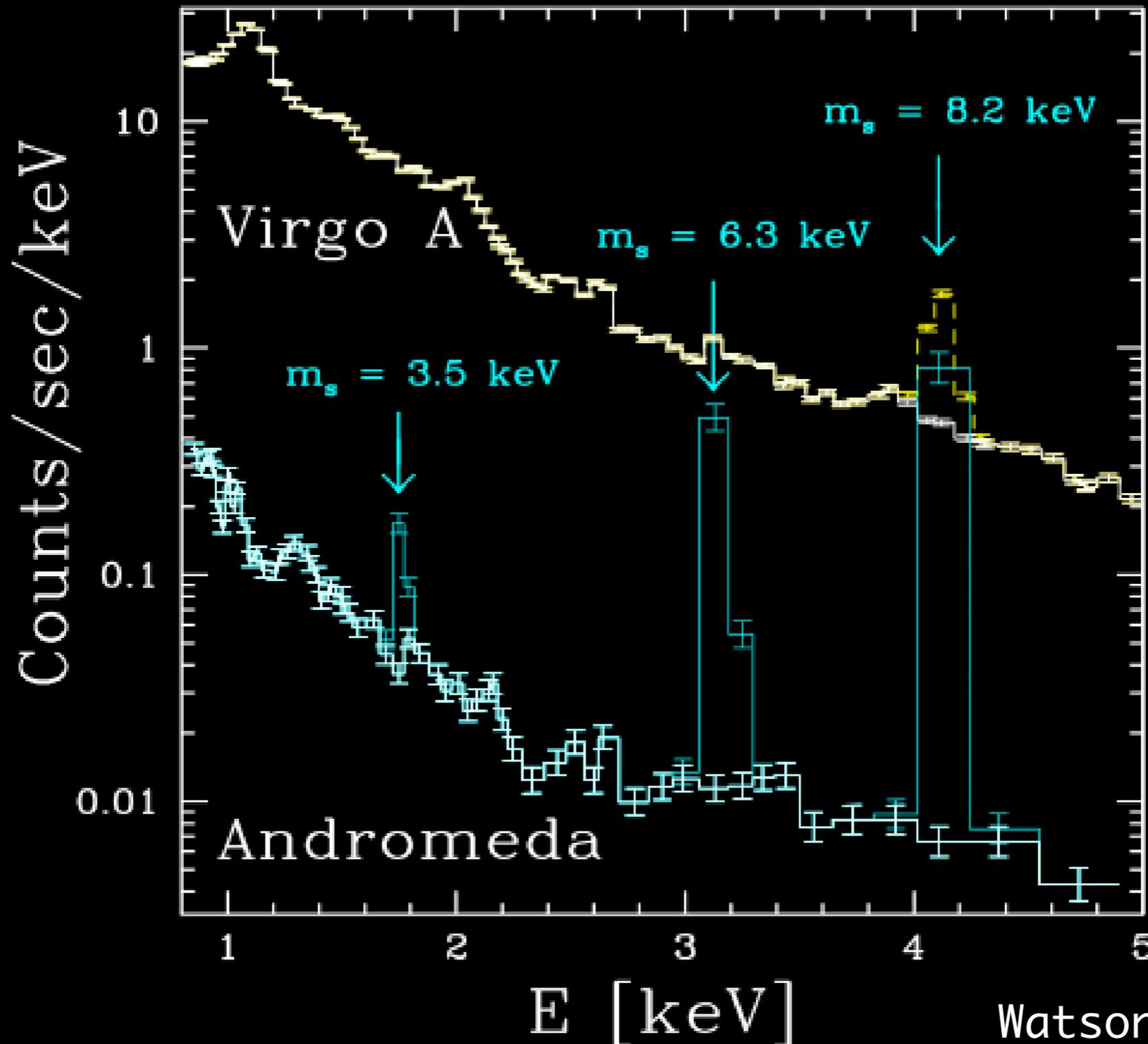
$$J[\Delta\Omega(\theta)] = \rho_s \int_0^{2\pi} d\phi \int_0^\theta \sin \theta' \left[\int_{x_{\min}(\theta')}^{x_{\max}(\theta')} I[\tilde{r}(x)] dx \right] d\theta'$$

$$I_{\text{NFW}}[\tilde{r}(x)] = \frac{1}{\tilde{r}(x) [1 + \tilde{r}(x)]^2}$$

$$I_{\text{BUR}}[\tilde{r}(x)] = \frac{1}{[1 + \tilde{r}(x)] [1 + \tilde{r}^2(x)]}$$



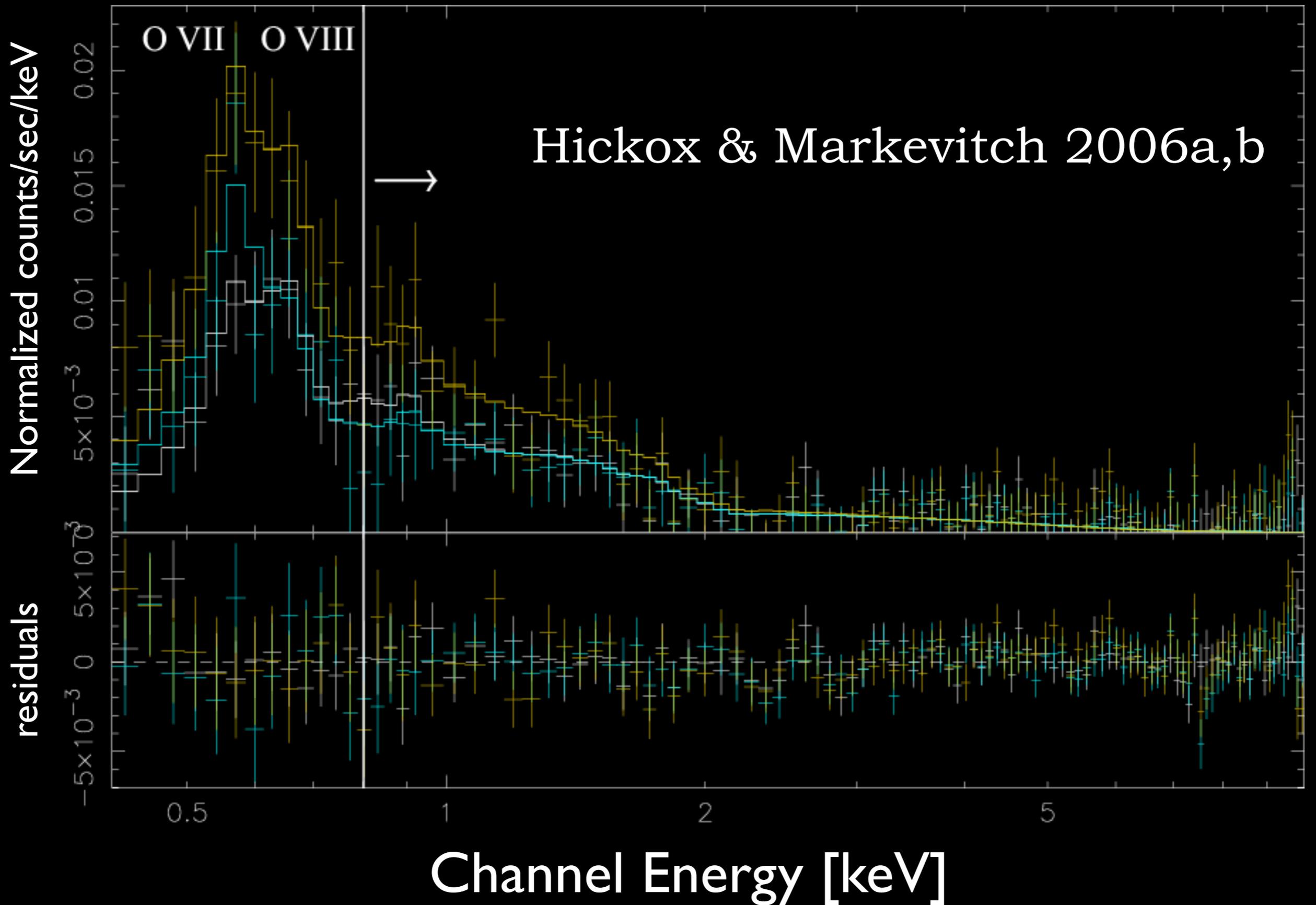
X-ray Limits: Virgo and M31



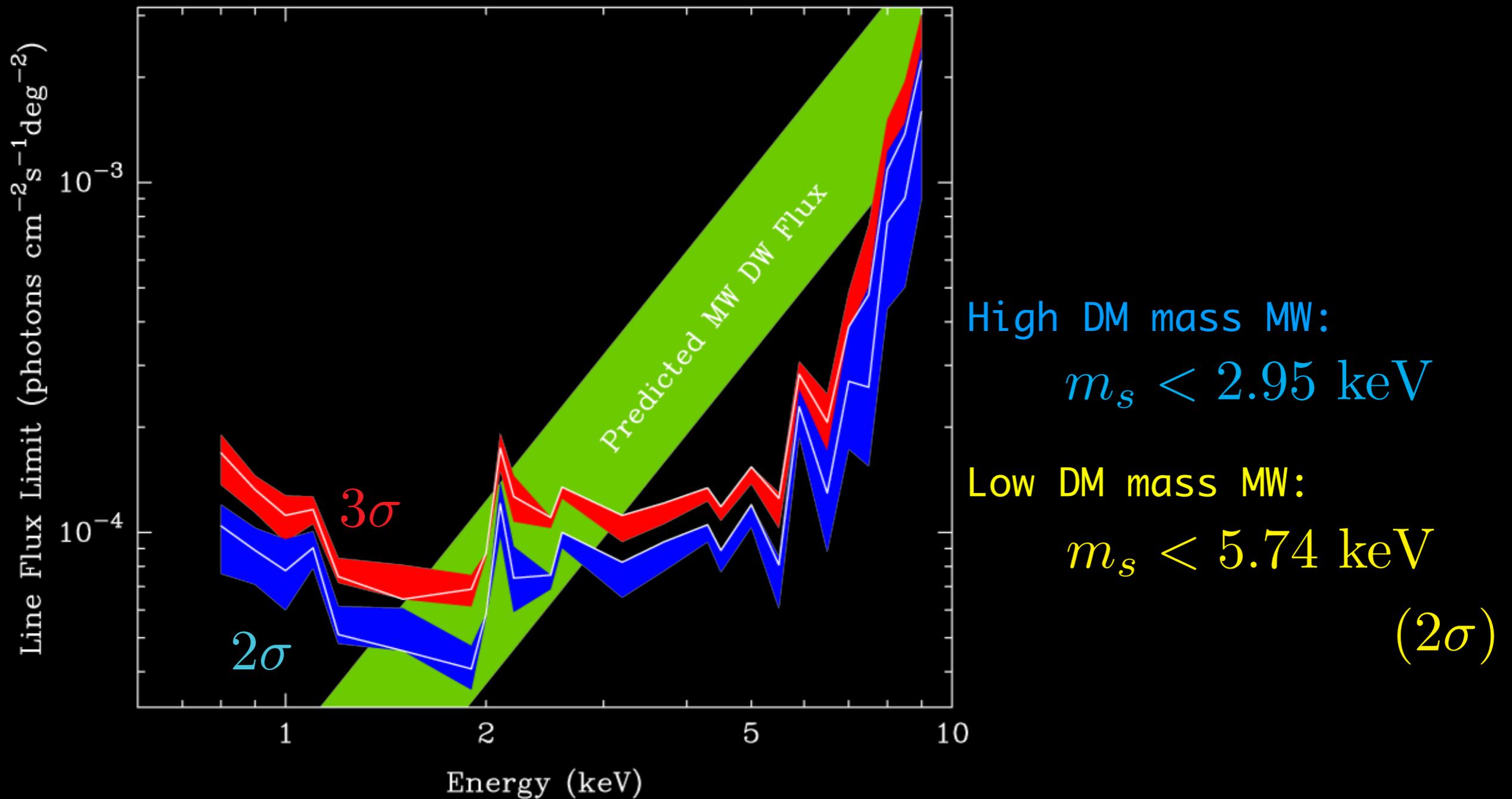
(XMM-Newton)

Watson et al (2006)
Abazajian et al (2001)

The (Unresolved) Cosmic X-ray Background



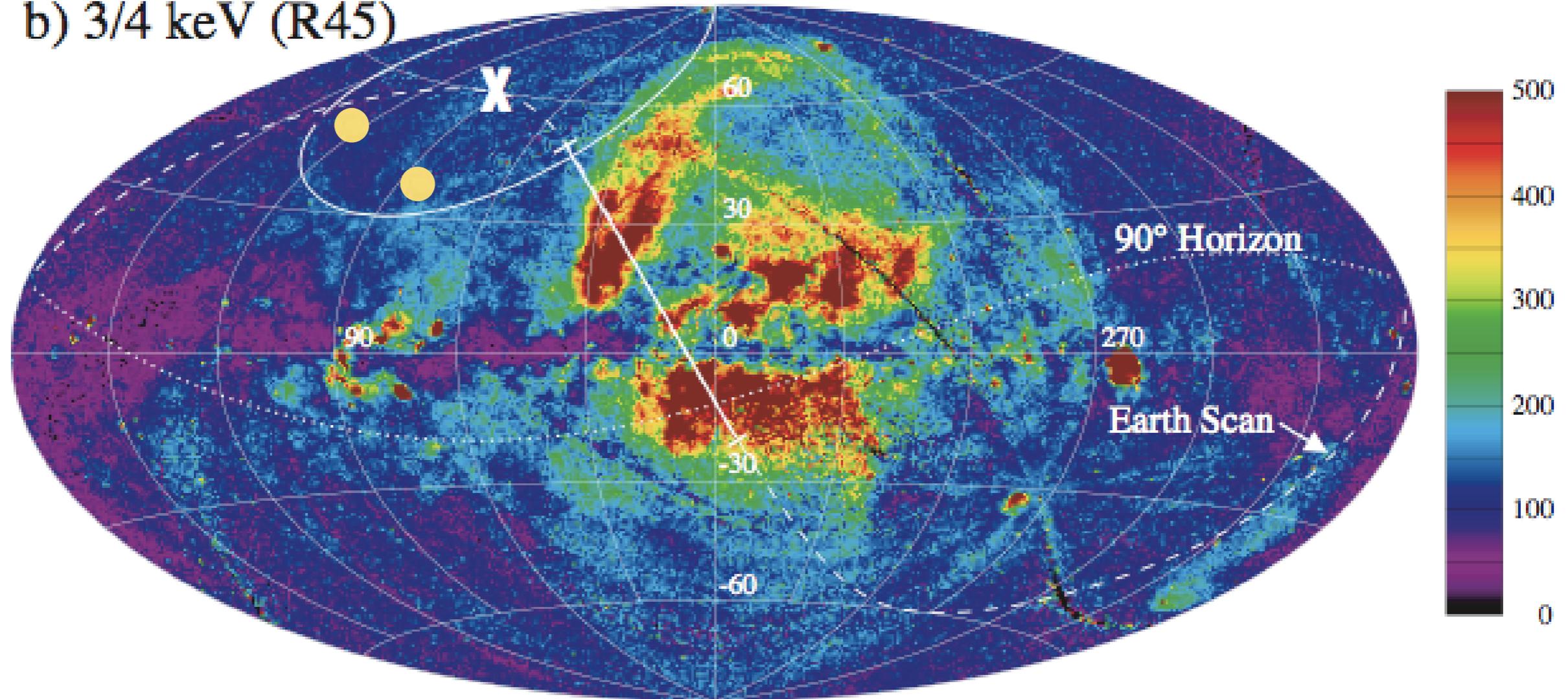
Milky Way Line Flux limits from the Chandra Deep Field of the CXB



Abazajian, Markevitch,
Koushiappas & Hickox 2006

The Soft X-ray Background

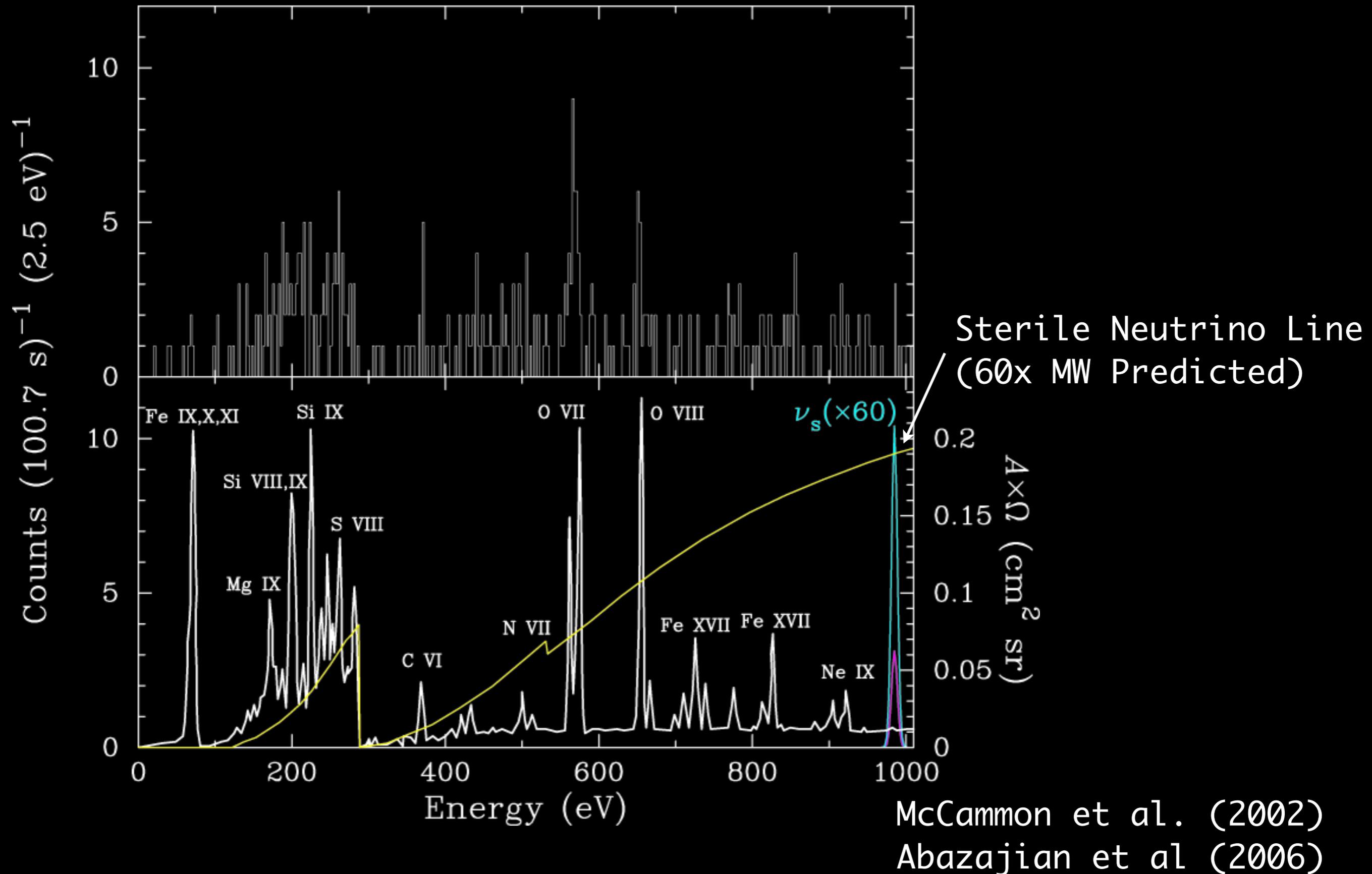
b) 3/4 keV (R45)

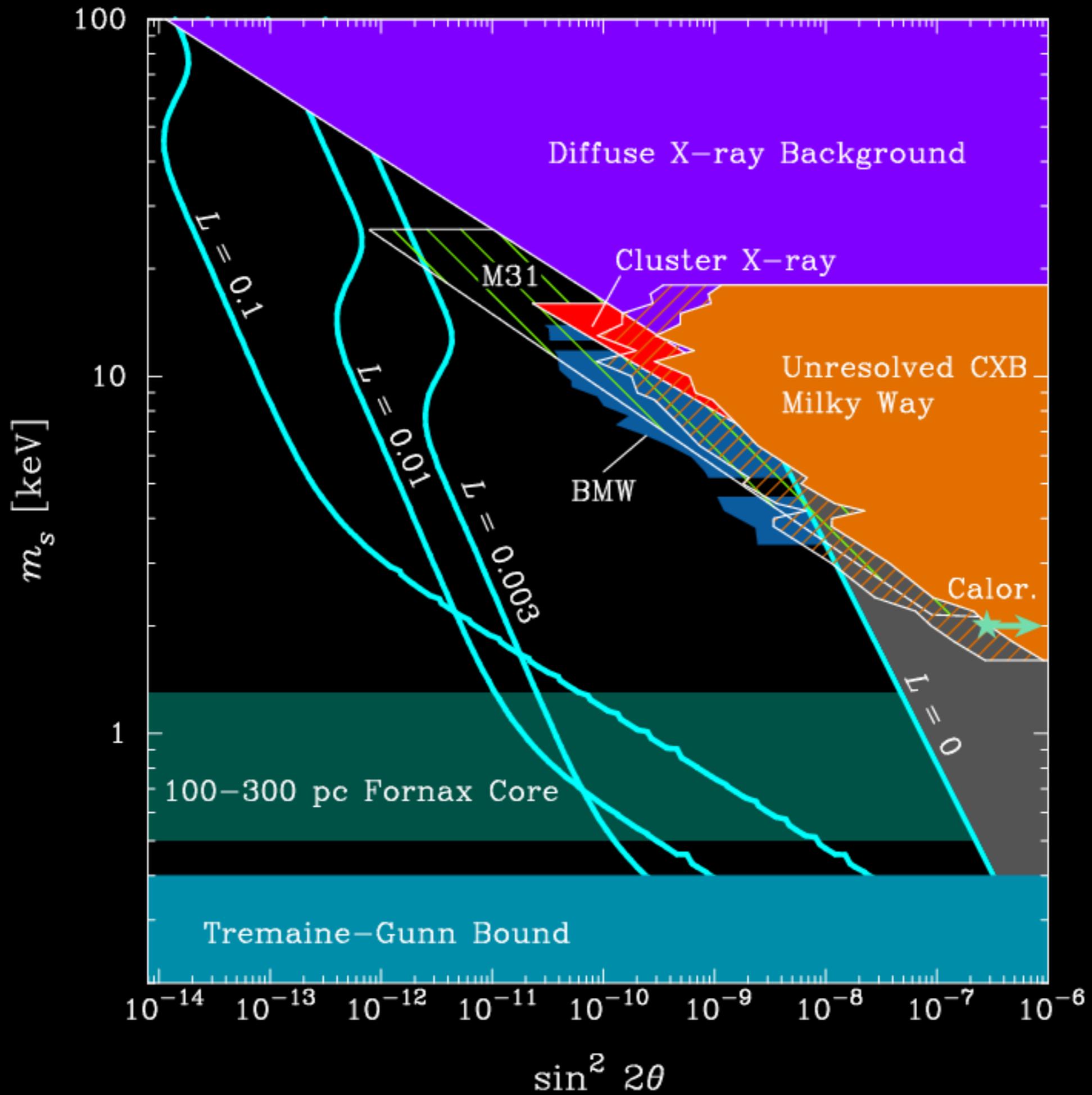


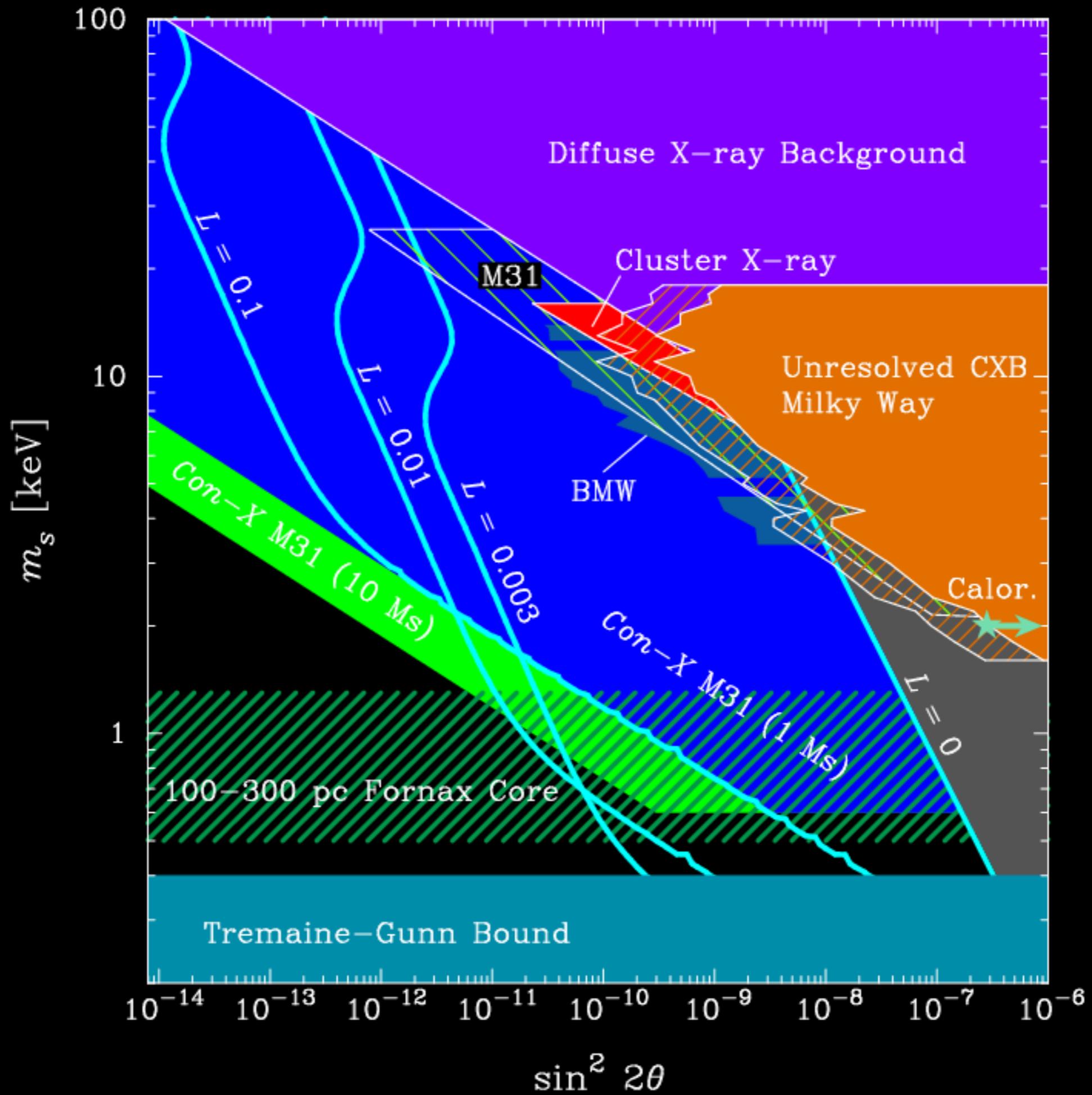
100.7 sec X-ray calorimeter exposure
on sounding rocket flight from
White Sands, NM

Using modern X-ray quantum calorimeters
Resolution ~ 9 eV FWHM
(McCammon et al., 2002)

The Soft X-ray Background: Spectrum







Summary

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- Yves Klein (1962): “Space will not be conquered by missiles... but by the *impregnation* of all of space with human sensibility.”